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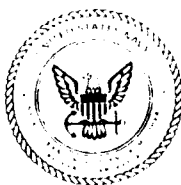


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## **ExperCAT Case Studies**

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# ABSTRACT

ExperCAT, an expert system that provides analysis and short-term forecasts (less than 6 hours) of clear air turbulence (CAT), is evaluated through an intercomparison with U.S. Air Force (USAF) turbulence charts. Seven case studies are presented. Using a meteorologist who was not involved in the development of ExperCAT as the end user for the test, five of the cases produced results that were in agreement with the USAF charts. A variety of possible reasons can explain the lack of agreement in the other two cases. These possibilities include the general type of coverage on the USAF charts as compared to the more detailed analysis of ExperCAT, an insufficient number of high quality satellite images, or an inadequate rule base in ExperCAT. Suggestions are made for system enhancements that would help the uninitiated user and expand the explanation facility of ExperCAT.

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## TABLE OF CONTENTS

1. Introduction.....	1
2. Data Description.....	2
3. Case Studies.....	2
3.1 Case 1.....	4
3.2 Case 2.....	7
3.3 Case 3.....	12
3.4 Case 4.....	14
3.5 Case 5.....	20
3.6 Case 6.....	26
3.7 Case 7.....	30
4. Conclusions and Recommendations.....	34
References.....	37

## **ExperCAT Case Studies**

### **1. Introduction**

ExperCAT is an expert system designed for the detection and prediction of clear air turbulence (CAT) (Peak, 1991; Perryman and Peak, 1991). Making primary use of satellite image interpretation, ExperCAT provides the user with a CAT intensity level and a confidence factor. Intensity levels include "Strong," "Moderate," "Light," and "No Significant CAT." The subjective confidence factors are obtained from the decision tree developed by Ellrod (1989). This decision tree acts as the backbone of ExperCAT by providing a majority of the expertise in its knowledge base.

Seven case studies are presented here using GOES satellite images and 300 mb charts. A meteorologist not involved in the development of ExperCAT was chosen to represent a typical user. Mr. Robin Brody of NRL Monterey volunteered his time and experience to be the expert system operator for this study. He was given no prior information about the seven cases and was not told beforehand whether or not turbulence was expected for each case. Supplied with Mr. Brody's interpretation of the available satellite imagery and upper air data, ExperCAT provides an analysis and short-term forecast for each case. This output is then compared with U.S. Air Force (USAF) turbulence charts. This intercomparison is used to help substantiate the expert system and reveal any problems or weaknesses during its use.

A brief description of the data and its acquisition is pro-

vided in section 2. A discussion of each case study is found in section 3. Conclusions and recommendations are presented in section 4.

## **2. Data Description**

USAF turbulence charts (e.g. Fig. 1) from April 1991, acquired by Mr. Dennis Perryman of NRL Monterey from the weather station at the Travis Air Force Base, were compared to the analysis and forecast provided by ExperCAT for each of the seven cases. These charts are maps with marked areas of expected turbulence (height and intensity). They are issued at a particular time (09Z or 21Z) and are valid for a 15 hour time period.

A collection of GOES satellite images from April 1991 was acquired through NRL Monterey and the Naval Postgraduate School (NPS). These photographs include visible, infrared, and 6.7  $\mu\text{m}$  water vapor images. An examination of the USAF turbulence charts in conjunction with the satellite imagery was necessary to find cases that would have a sufficient number of images to enable a reasonable simulation run of ExperCAT. Seven such cases were found.

After the cases were selected, 300 mb analyses of the areas of interest were obtained through the METLAB at NRL Monterey. Each analysis included height contours, isotherms, and wind barbs drawn on each map.

## **3. Case Studies**

The following subsections provide a discussion of each of

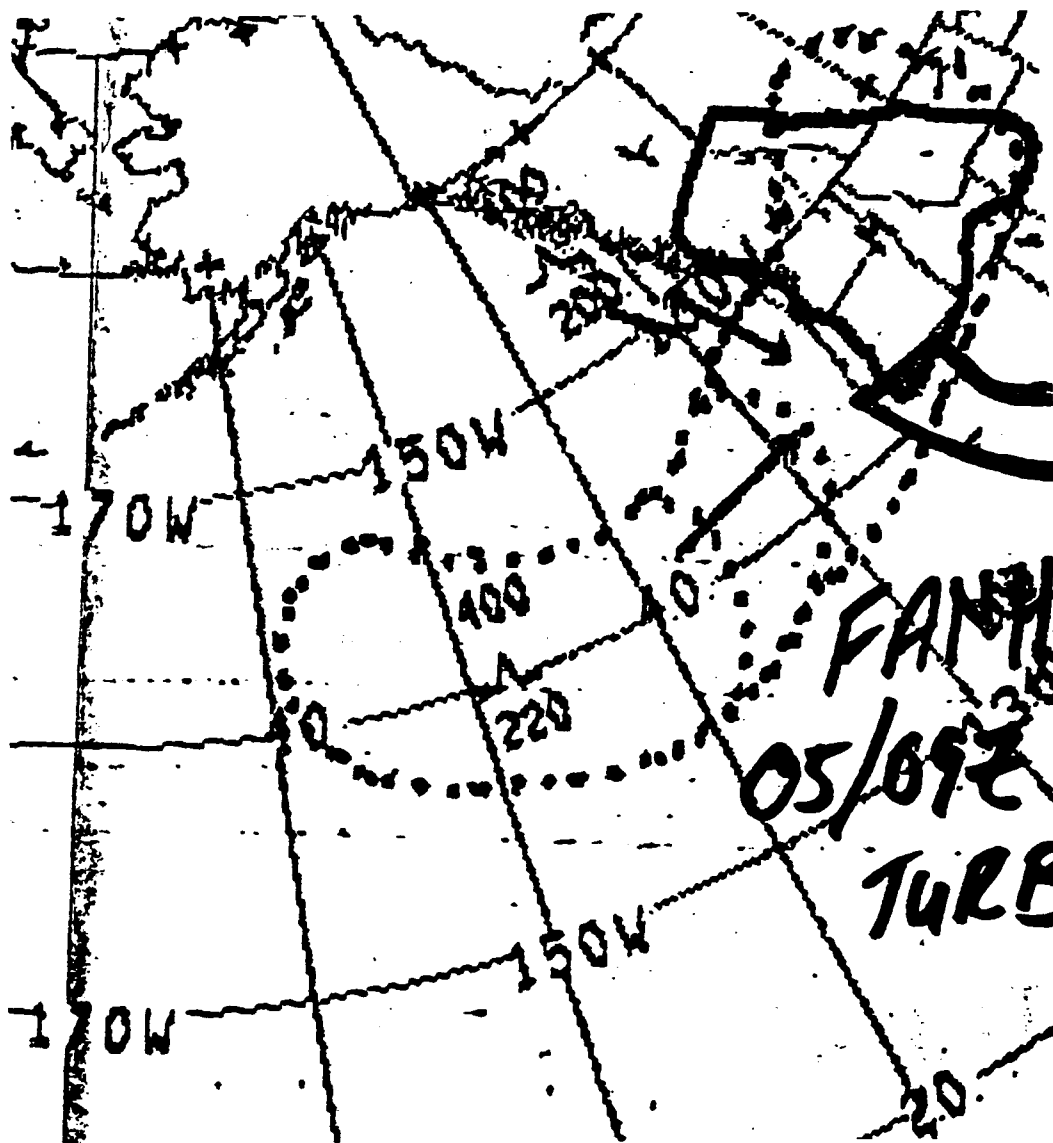


Figure 1. U.S. Air Force turbulence chart valid for 09Z, 5 Apr 91 to 00Z, 6 Apr 91. For each of these figures the dashes outline the turbulent area with the top and bottom levels of the layer listed in hundreds of feet. The intensity is also marked by one of the following:  
 ^ - light, ~ - moderate, > - strong.

the seven cases. Included in each discussion is a synopsis of the interactive session between Mr. R. Brody and ExperCAT.

### 3.1 Case 1

Moderate turbulence (22,000 ft to 40,000 ft) was indicated for an area above the Pacific Ocean (approx. 140W, 40N) and valid from 09Z on 5 Apr 91 to 00Z on 6 Apr 91 (Figure 1). Various satellite images (GOES) from 15Z Apr 4 to 0830Z Apr 5 were available, as well as 300 mb charts from 12Z Apr 4 and 00Z Apr 5. A 300 mb analysis from 12Z Apr 5 was also available to be used as a map of forecasted data.

Using 09Z on Apr 5 as the session time, a short-term forecast (less than 6 hrs.) was made by ExperCAT. Part of the interactive session between Mr. Brody (referred to as RB from here on) and ExperCAT evolved as follows, with references to some of the data used:

Question 1: Which describes the upper synoptic flow pattern?

RB: Straight or slightly curved flow (Figure 2)

2: Do you see either of these cirrus signatures? (referring to bands or billows, or ragged edge)

RB: Neither cirrus signature (Figure 3)

3: Is the flow confluent?

RB: Not confluent flow (Figure 2)

4: Does the region have mountains?

RB: Smaller, less-steep mountains or flat terrain (best choice for ocean location)

ExperCAT forecast: No significant CAT, 80% confidence

Why the discrepancy between ExperCAT and the USAF chart?



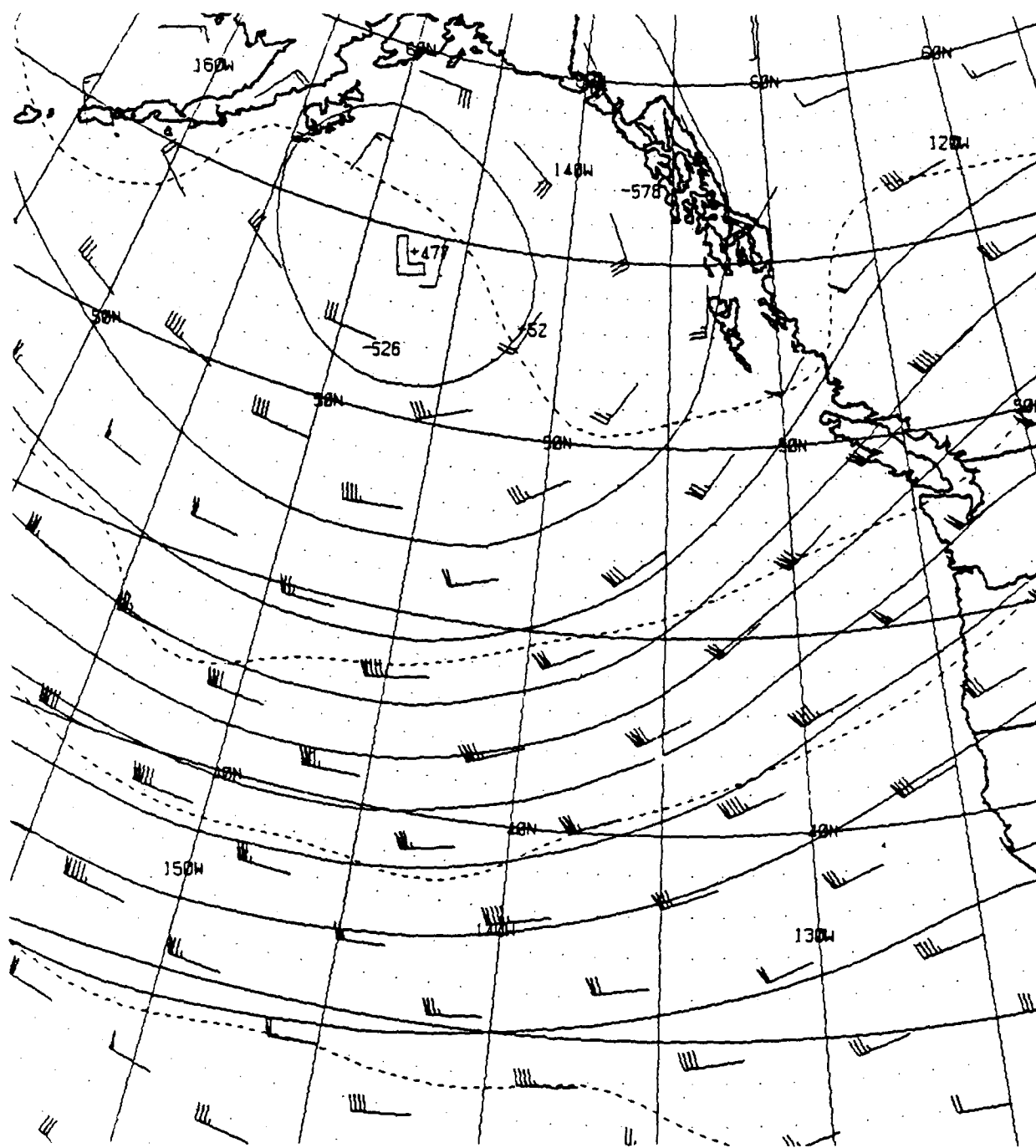


Figure 2. 300 mb analysis for 00Z, 5 Apr 91. For each of these figures the solid lines are height contours and the dashed lines are isotherms with wind barbs also displayed.



Figure 3. GOES infrared image for 0831Z, 5 Apr 91.

One possible explanation is that ExperCAT performs a more detailed analysis of the situation. This analysis involves a search for specific satellite signatures in a localized area. The USAF chart contains more of a general marking of a large region where localized areas of CAT can be expected during the listed time period. On the other hand, however, the rule base in ExperCAT may not be sufficient in detecting CAT in every instance. Another possible explanation is that the available images (not all of which are presented here) are inadequate in number and/or quality such that the appropriate signatures are not discernible.

### **3.2 Case 2**

Moderate turbulence (20,000 ft to 38,000 ft) was marked for an area above the Pacific Ocean (approx. 145W, 45N) and valid from 21Z on 11 Apr 91 to 12Z on 12 Apr 91 (Figure 4). GOES images from 0230Z to 20Z on Apr 11 were available. In addition, 300 mb analyses from 00Z and 12Z on Apr 11 and a "forecast" 300 mb chart from 00Z Apr 12 were also available.

Based on the interpretation of this data a short-term forecast (session time: 21Z Apr 11) was made by ExperCAT. The following is the interactive session:

Question 1: Which describes the upper synoptic flow pattern?

RB: Sharply curved (Figure 5)

2: Which type of sharply curved flow?

RB: Trough (Figure 5)

3: Which of these are present?

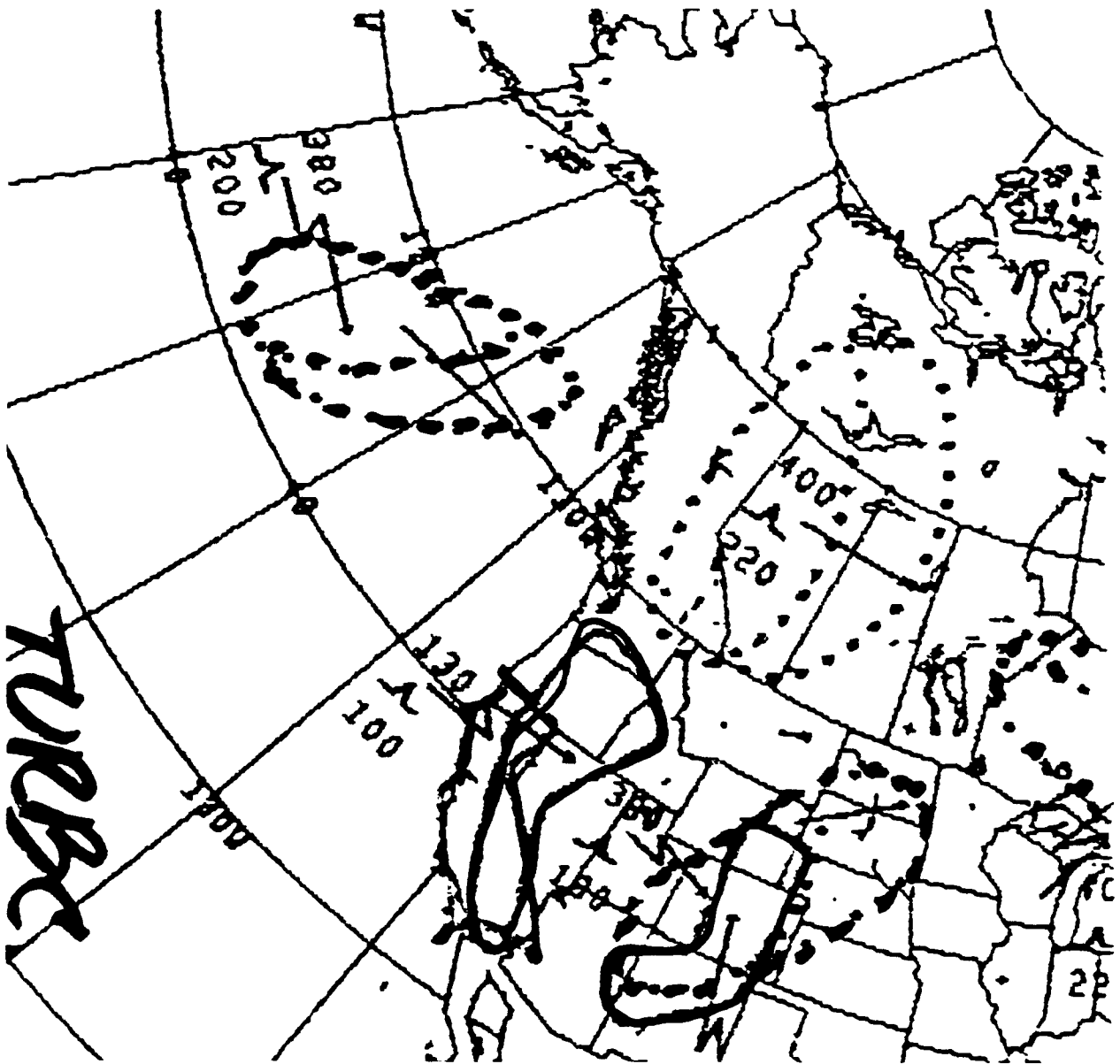


Figure 4. U.S. Air Force turbulence chart valid for 21Z, 11 Apr 91 to 12Z, 12 Apr 91.

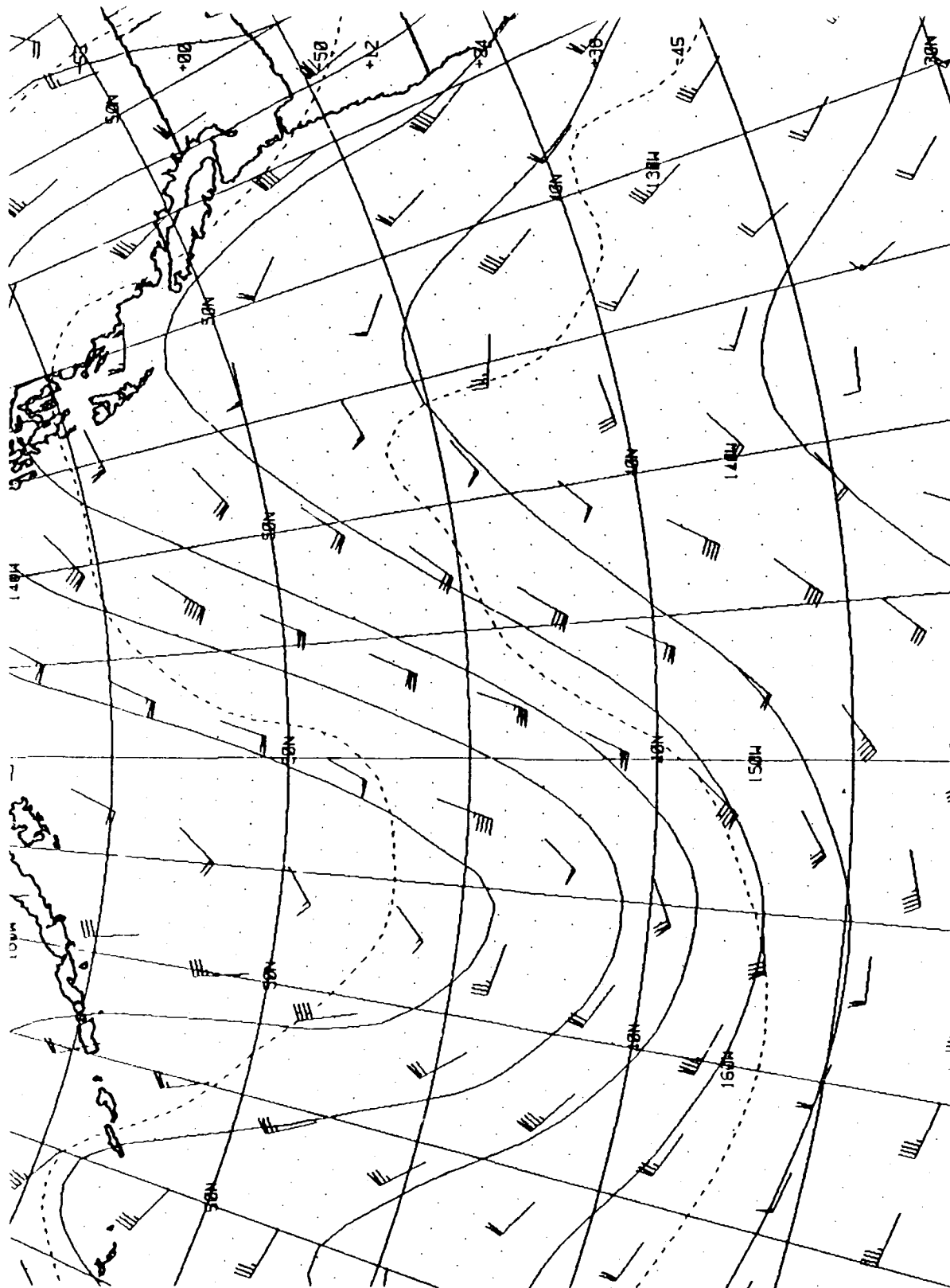


Figure 5. 300 mb analysis for 12Z, 11 Apr 91.

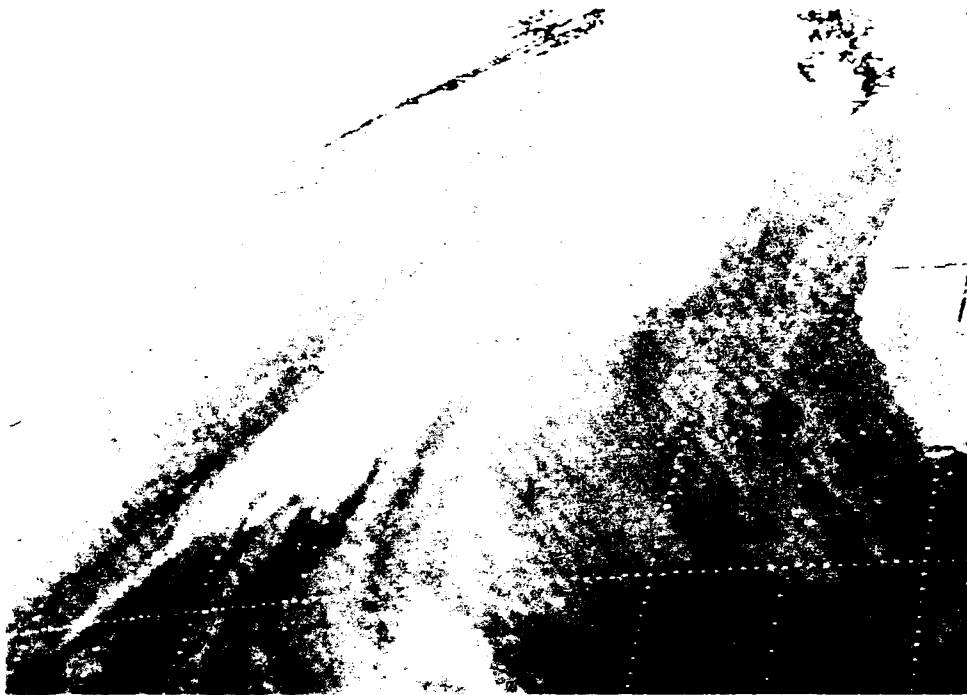


Figure 6. GOES infrared image for 1231Z, 11 Apr 91.

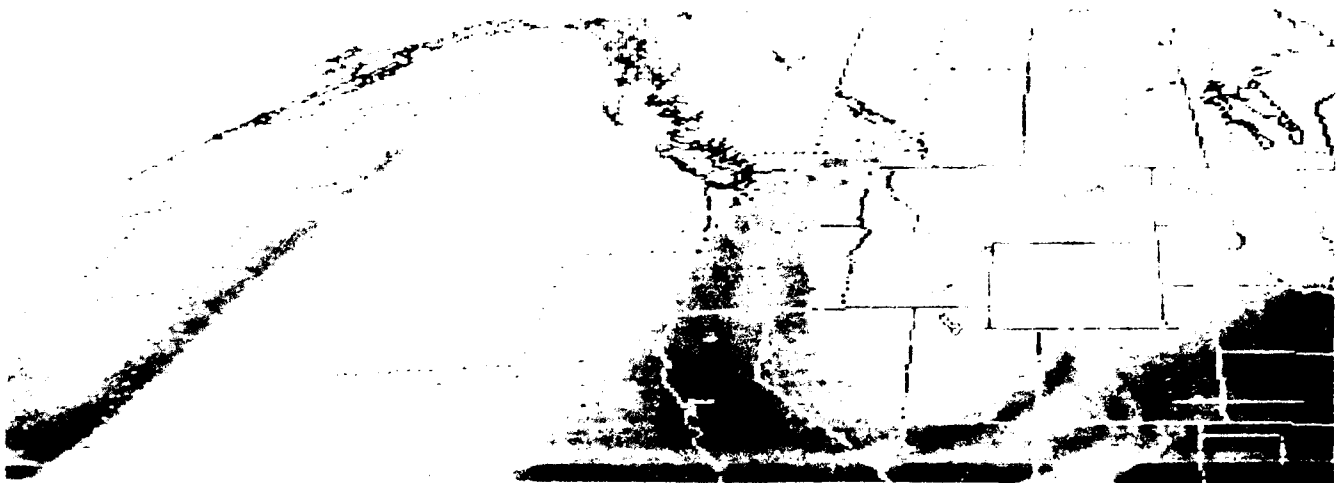


Figure 7a. GOES water vapor image for 1501Z, 11 Apr 91.

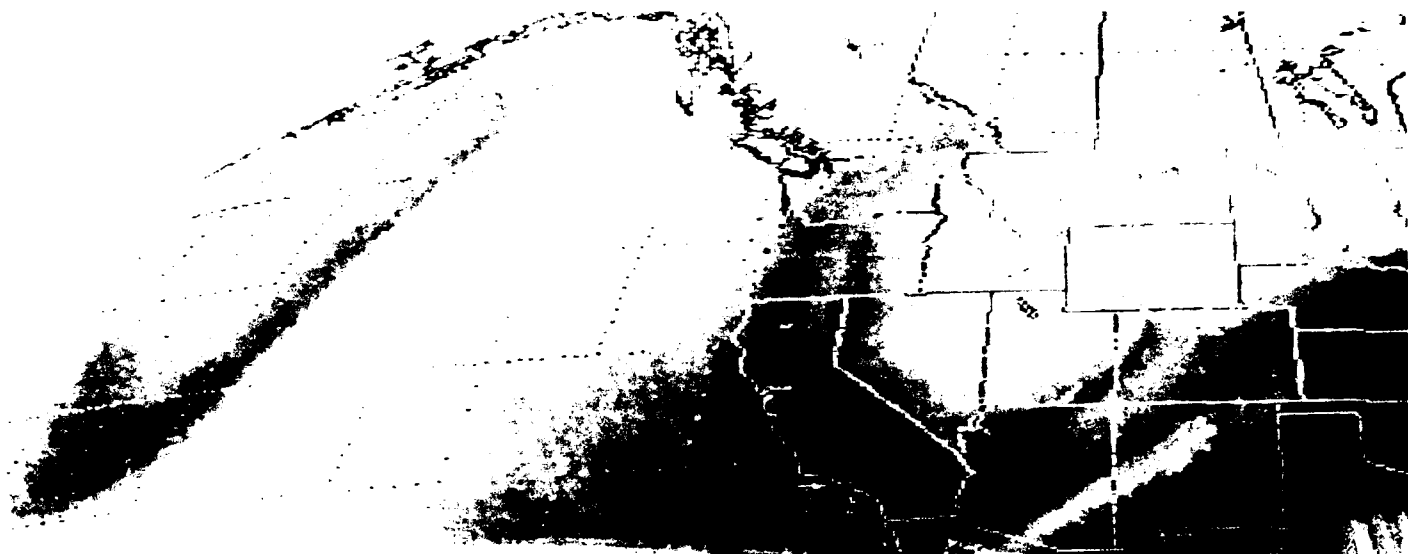


Figure 7b. GOES water vapor image for 1601Z, 11 Apr 91.

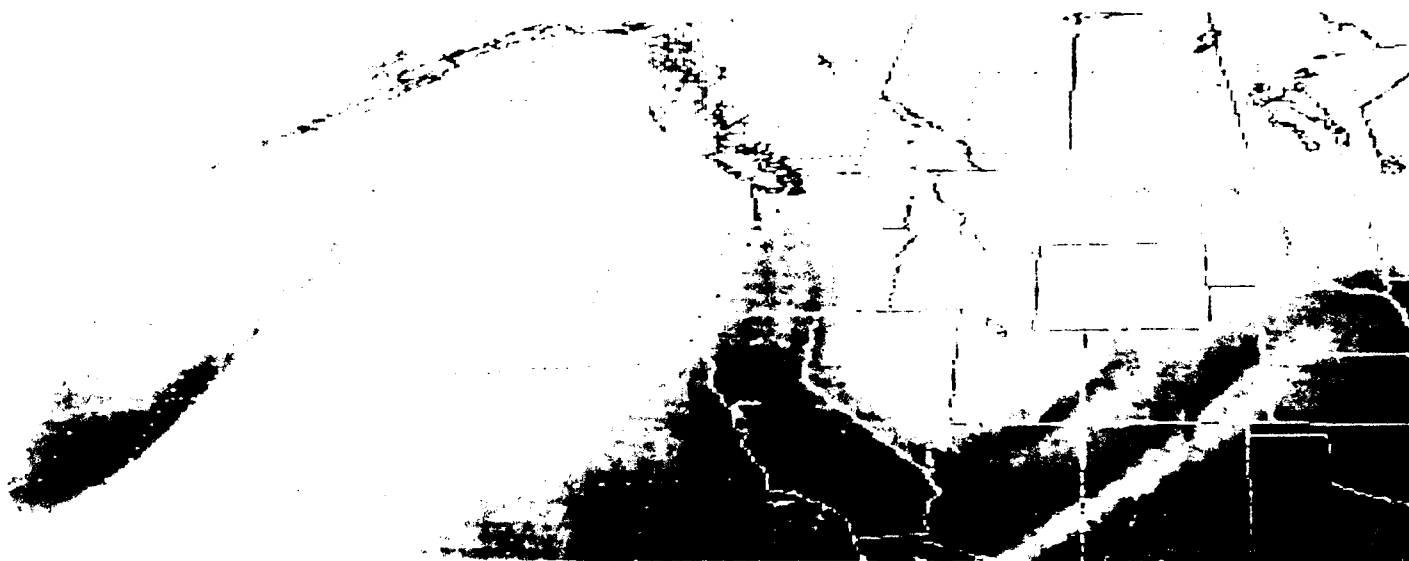


Figure 7c. GOES water vapor image for 1701Z, 11 Apr 91.

RB: Both a sharp cirrus edge (Figure 6) and darkening zone (water vapor) (Figure 7a-c)

ExperCAT forecast: Moderate or greater, 80% confidence

This forecast is in agreement with the turbulence chart.

Additionally, satellite photos (Figures 8 and 9) taken during the valid time of the USAF chart reveal a continuation of these satellite signatures.

The author subsequently examined a region to the southeast (approx. 140W, 40N) of the area of marked turbulence discussed above. The following is the interactive session:

Question 1: Which describes the upper synoptic flow pattern?

Author: Sharply curved (Figure 5)

2: Which type of sharply curved flow?

Author: Ridge (Figure 5)

3: Are there well-defined transverse bands near the upper ridge axis?

Author: Transverse bands absent (Figure 6)

4: Does the region have mountains?

Author: Smaller, less-steep mountains or flat terrain

ExperCAT forecast: No significant CAT, 80% confidence

This forecast is in agreement with the USAF turbulence chart since the region in question is outside the marked area.

### 3.3 Case 3

Moderate turbulence (22,000 ft to 40,000 ft) was marked for an area above southern Alberta, Canada (approx. 112W, 52N) and valid for the same time period as case 2 (Figure 4). Similar satellite and upper air data were also available. The interactive session (time: 21Z Apr 11) follows:



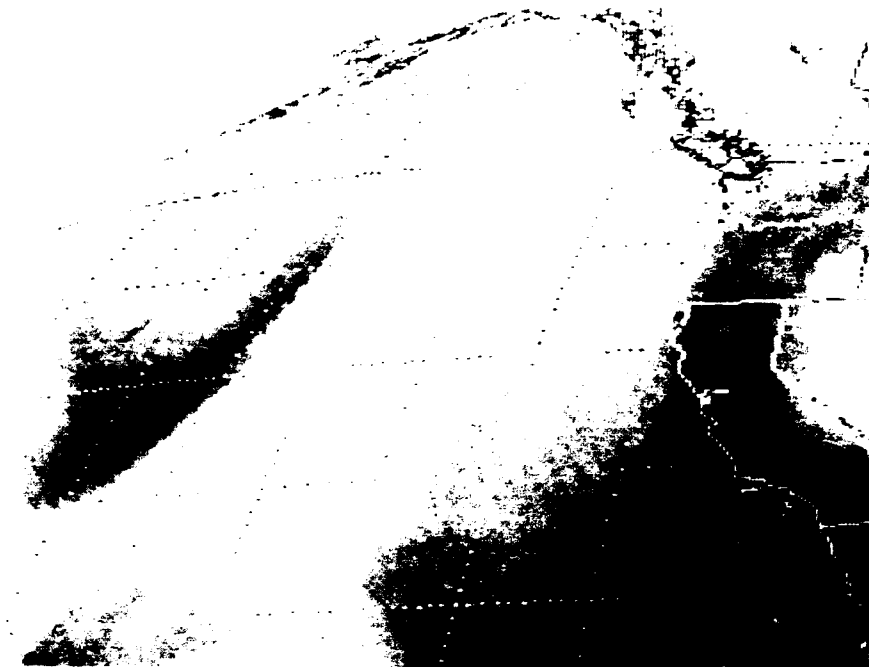


Figure 8. GOES water vapor image for 2201Z, 11 Apr 91.

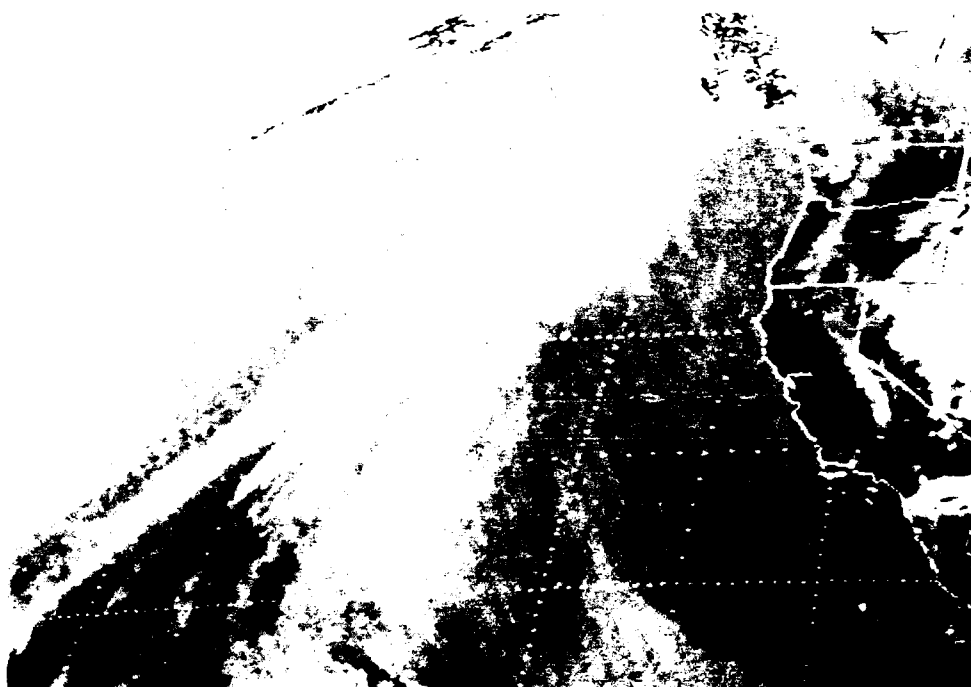


Figure 9. GOES infrared image for 2331Z, 11 Apr 91.

Question 1: Which describes the upper synoptic flow pattern?

RB: Hyperbolic (Figure 10)

2: Which cloud feature is present?

RB: Little or no cloudiness (Figure 11)  
(determined to be most appropriate selection)

3: Is darkening with time occurring in the water vapor image?

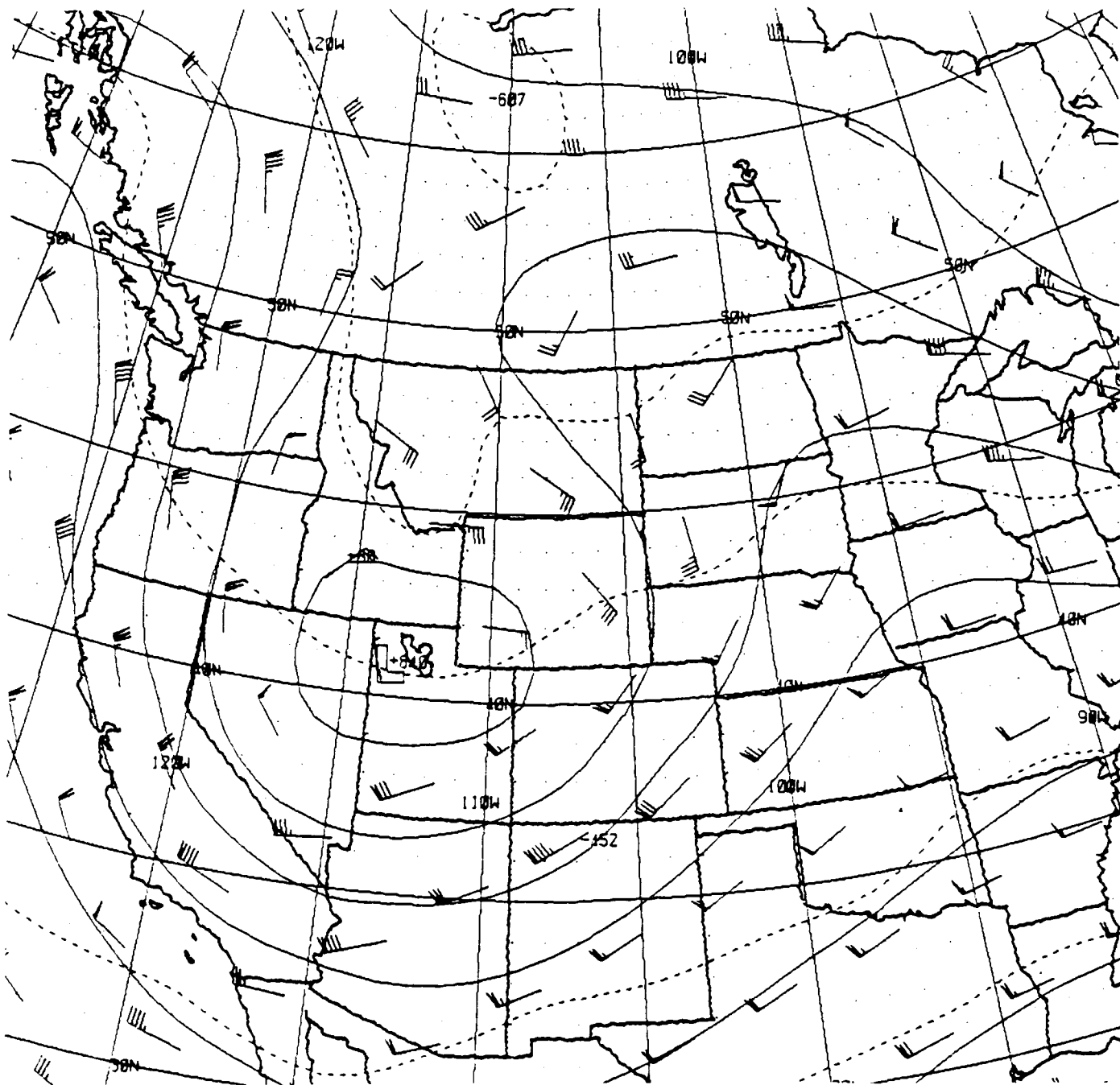
RB: No darkening with time (Figure 7a-c)

ExperCAT forecast: No significant CAT, 80% confidence

The disagreement between ExperCAT and the USAF chart may be a result of the interpretation of which cloud feature is present (Question 2, above) in the area of interest. One could interpret from the available images that the northern edge of a comma cloud head is a feature worth noting. This comma head appears to be flattening with time near the location in question. See Figure 12a-b. This would be considered an area of CAT by the expert system. This flattening is even more noticeable on imagery after the session time (Figure 13). As in case 1, ExperCAT may be suggesting a smaller region(s) of CAT than the indicated area of turbulence on the USAF chart.

#### **3.4 Case 4**

Moderate turbulence (20,000 ft to 40,000 ft) was indicated for an area just north of North Dakota and Minnesota (approx. 95W, 50N) and valid from 21Z on 13 Apr 91 to 12Z on 14 Apr 91 (Figure 14). GOES images from 1230Z to 20Z on 13 Apr were available along with 300 mb charts from 00Z and 12Z on Apr 13 and a "forecast" chart from 00Z Apr 14. ExperCAT provided a short-term forecast (session time: 21Z Apr 13) based on this data. The



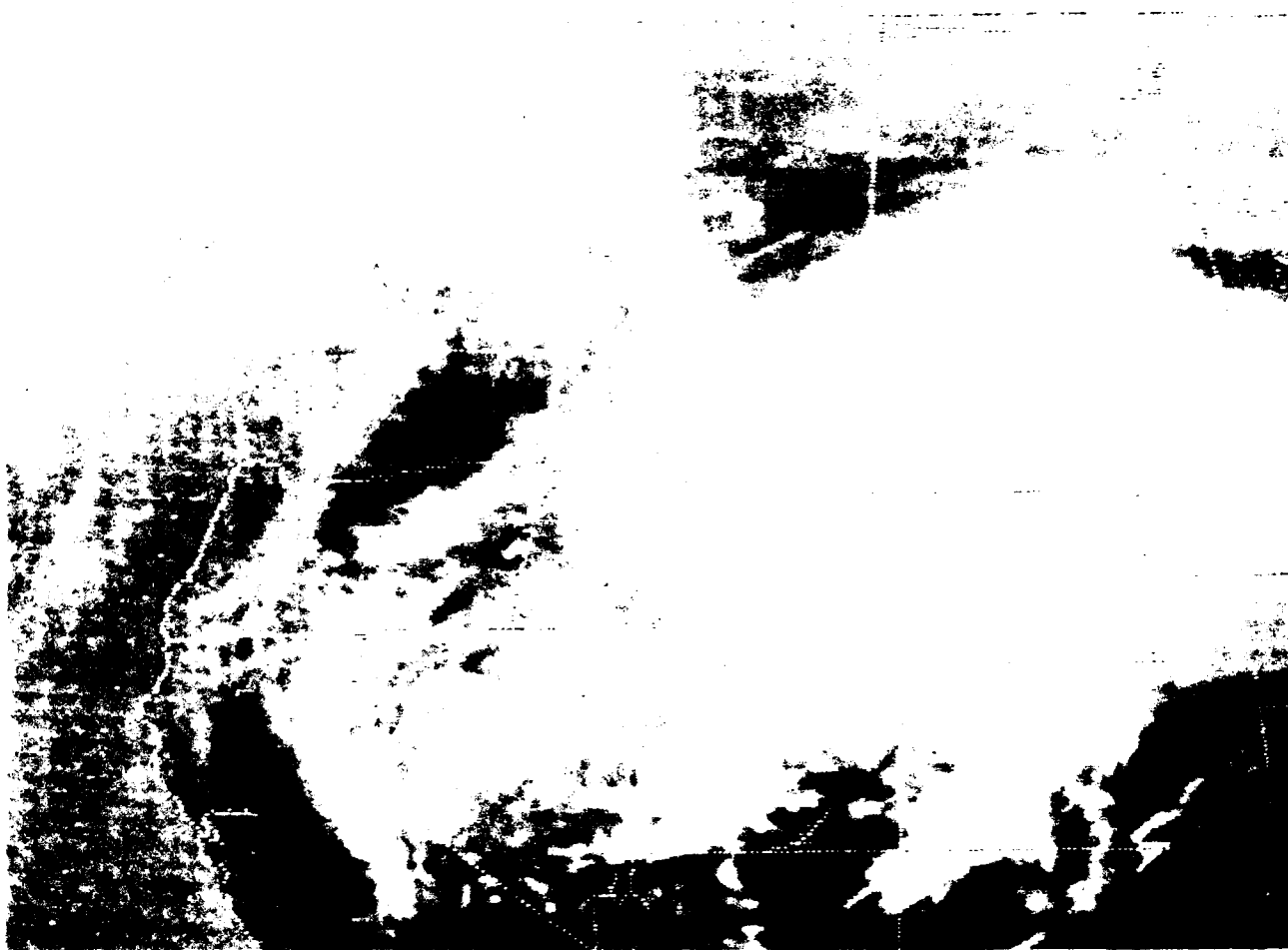


Figure 11. GOES infrared image for 1701Z, 11 Apr 91.

Figure 11a. NES infrared image for 0101Z, 11 Apr 91.



Figure 12b. GOES infrared image for 2001Z, 11 Apr 91.

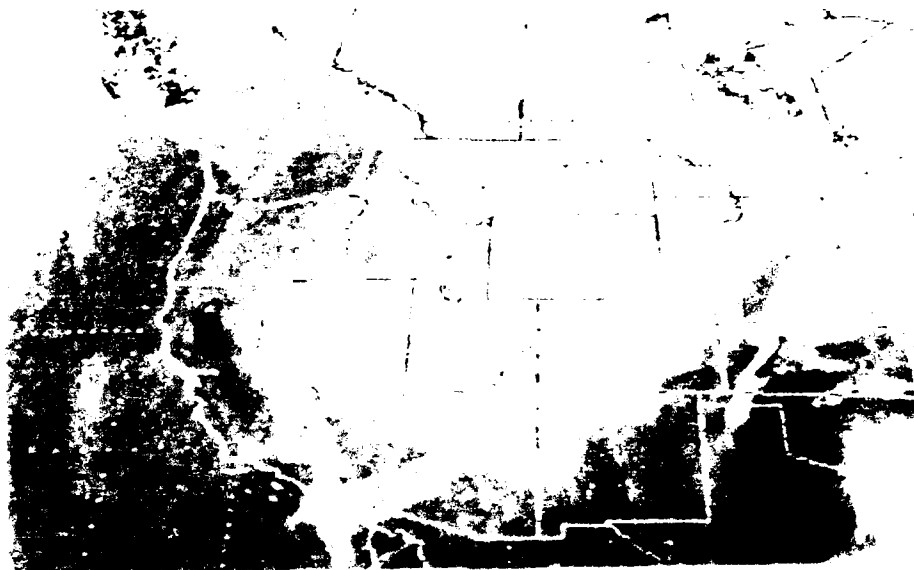


Figure 13. GOES infrared image for 0231Z, 12 Apr 91.

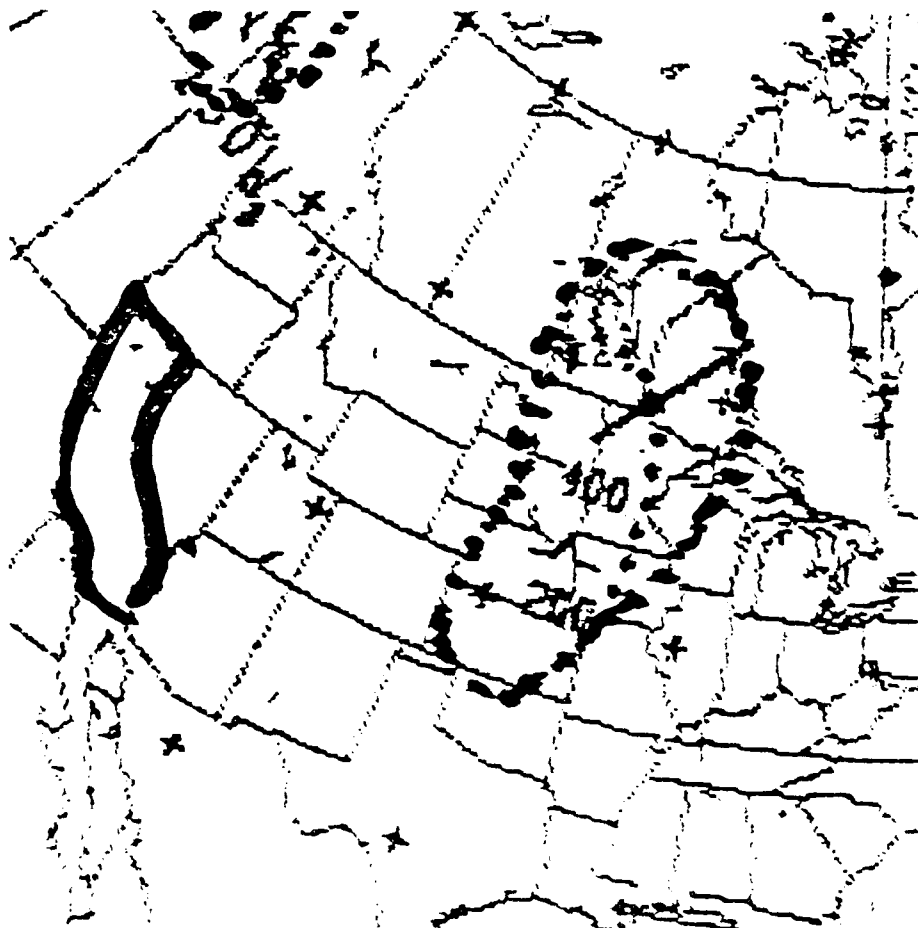


Figure 14. U.S. Air Force turbulence chart valid for  
21Z, 13 Apr 91 to 12Z, 14 Apr 91.

interactive session:

Question 1: Which describes the upper synoptic flow pattern?

RB: Hyperbolic (Figure 15)

2: Which cloud feature is present?

RB: Comma cloud (Figure 16)

3: Where is the forecast location with respect to the comma cloud?

RB: Near the poleward edge of the comma head (Figure 16)

4: Describe the synoptic situation.

RB: Deepening or steady-state upper-level low center

5: Which type of comma system is present?

RB: Sheared comma (the jet crosses over the cloud head)

6: Are these sheared-comma features present?

RB: Sharp, anticyclonically-curved jet cirrus segments (Figure 17)

ExperCAT forecast: Moderate or greater, 80% confidence

This forecast is in agreement with the USAF turbulence chart (Figure 14).

### 3.5 Case 5

In the southern portion (approx. 100W, 40N) of the turbulent region marked for case 4 (Figure 14) a different type of satellite signature and flow pattern can be found to produce the same forecast. The interactive session:

Question 1: Which describes the upper synoptic flow pattern?

RB: Sharply curved (Figure 15)

2: Which type of sharply curved flow?





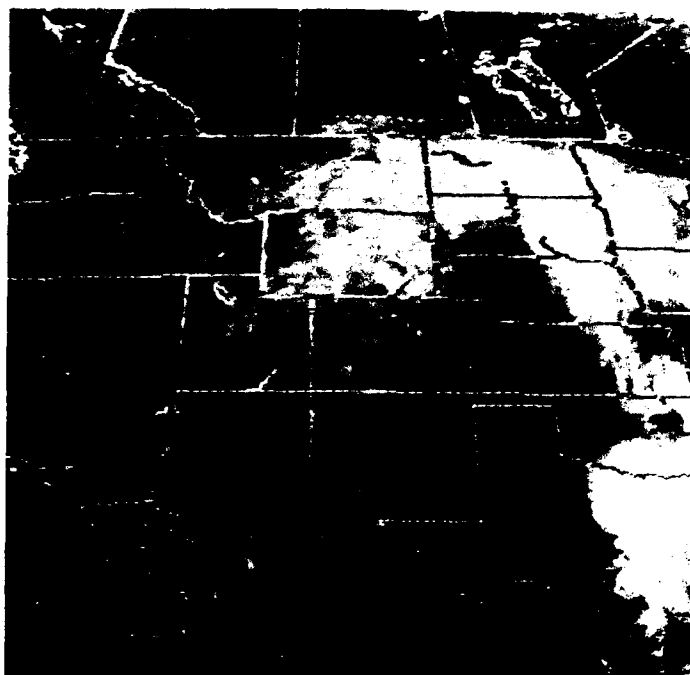


Figure 16. GOES visible image for 1601Z, 13 Apr 91.

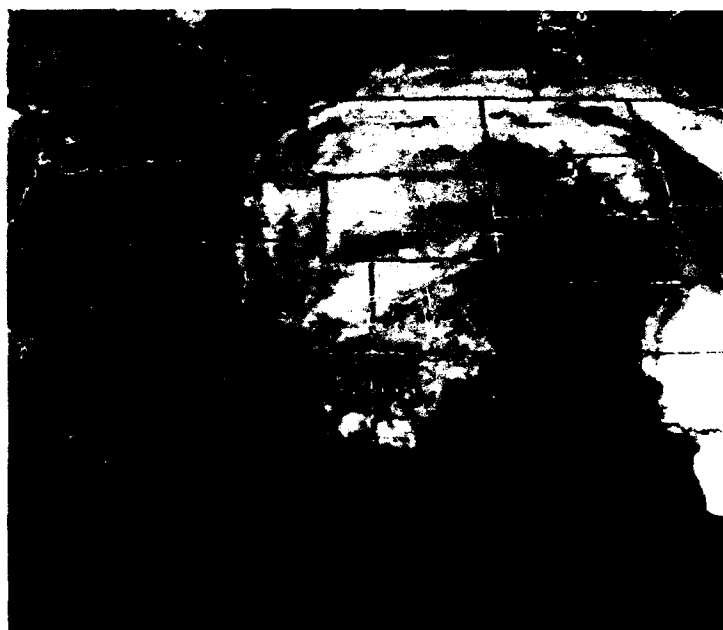


Figure 17. GOES infrared image for 1831Z, 13 Apr 91.

RB: Trough (Figure 15)

3: Which of these are present?

RB: Darkening zone in water vapor image along or upstream from trough (Figure 18a-c)

ExperCAT forecast: Moderate or greater, 80% confidence

Using the same data, the author examined an area in eastern Colorado (approx. 103W, 39N) that was outside the marked region on the USAF turbulence chart (Figure 14). The following is the interactive session:

Question 1: Which describes the upper synoptic flow pattern?

Author: Sharply curved (Figure 15)

2: Which type of sharply curved flow?

Author: Trough (Figure 15)

3: Which of these are present?

Author: Neither a sharp cirrus edge nor a darkening zone (Figure 18a-c)

4: Describe the cold-air side of the cirrus.

Author: Straight or cyclonic curvature

5: Which best describes the cloud bands?

Author: Not wide, thick and carrot-shaped

ExperCAT forecast: Light-to-Moderate, 70% confidence

The discrepancy between this forecast and the USAF turbulence chart appears to be a result of a problem in the rule base. The line of questioning during the interactive session indicates the system was assuming the presence of banded cirrus. An update to the Ellrod (1989) decision tree suggests that in some sharply curved trough situations ragged, transverse-banded cirrus is present and strong CAT may occur. However, ExperCAT should not

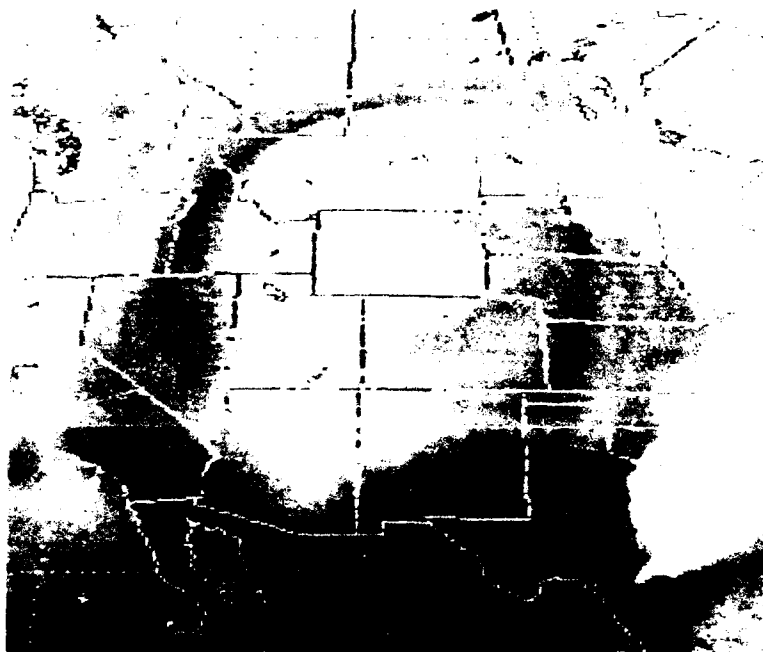


Figure 18a. GOES water vapor image for 1501Z, 13 Apr 91.

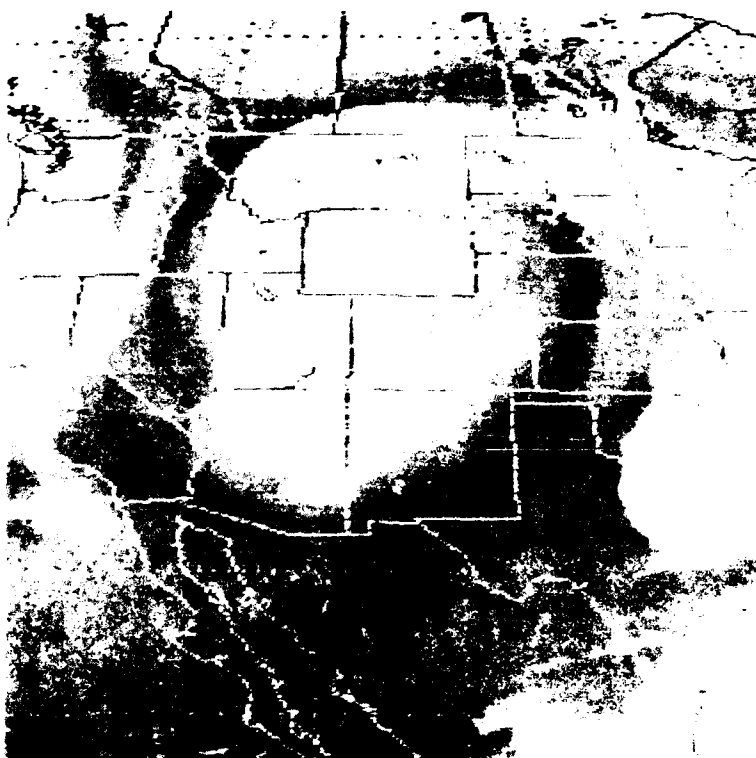


Figure 18b. GOES water vapor image for 1601Z, 13 Apr 91.

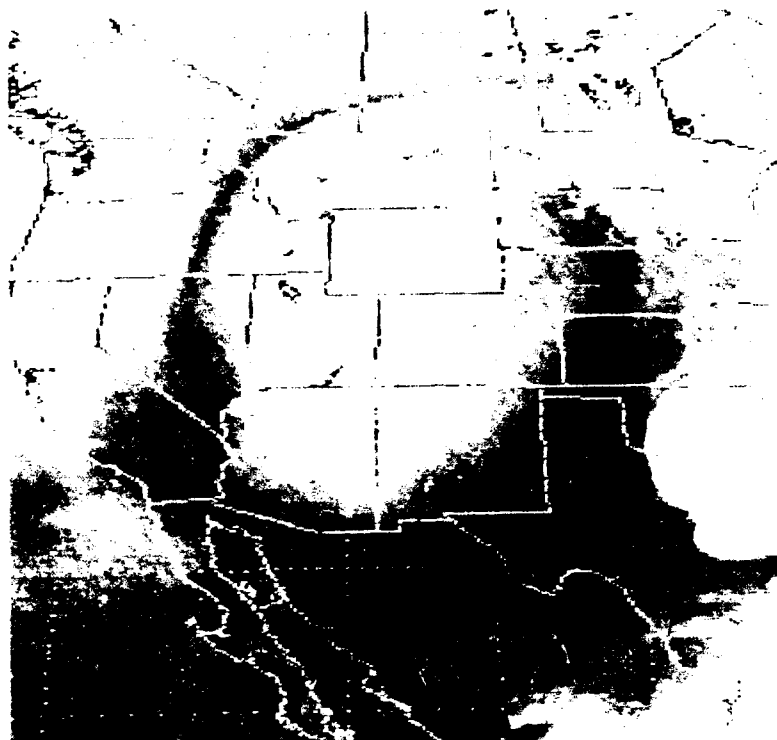


Figure 18c. GOES water vapor image for 1701Z, 13 Apr 91.



Figure 19. U.S. Air Force turbulence chart valid for 21Z, 15 Apr 91 to 12Z, 16 Apr 91.

assume that these bands are always present. One solution to this problem is the insertion of the question "Are ragged, transverse-banded cirrus present?". A "No" response would yield the forecast: "No significant CAT."

### 3.6 Case 6

Moderate turbulence (20,000 ft to 38,000 ft) was marked for an area above the Pacific Ocean (approx. 150W, 45N) and valid from 21Z on 15 Apr 91 to 12Z on 16 Apr 91 (Figure 19). GOES images from 17Z to 2330Z on 15 Apr were available along with a 300 mb chart from 12Z on Apr 15 and a "forecast" chart from 00Z on Apr 16. The interactive session (time: just before 00Z Apr 16):

Question 1: Which describes the upper synoptic flow pattern?

RB: Sharply curved (Figure 20)

2: Which type of sharply curved flow?

RB: Trough (Figure 20)

3: Which of these are present?

RB: Both a sharp cirrus edge (Figure 21) and a darkening zone (water vapor) (Figure 22a-b)

ExperCAT forecast: Moderate or greater, 80% confidence

The USAF turbulence chart (Figure 19) and ExperCAT are in agreement. As in case 2, an examination of a region to the southeast (approx. 140W, 40N) produces an agreement with the turbulence chart for an area of no CAT. The following is the interactive session:

Question 1: Which describes the upper synoptic flow pattern?

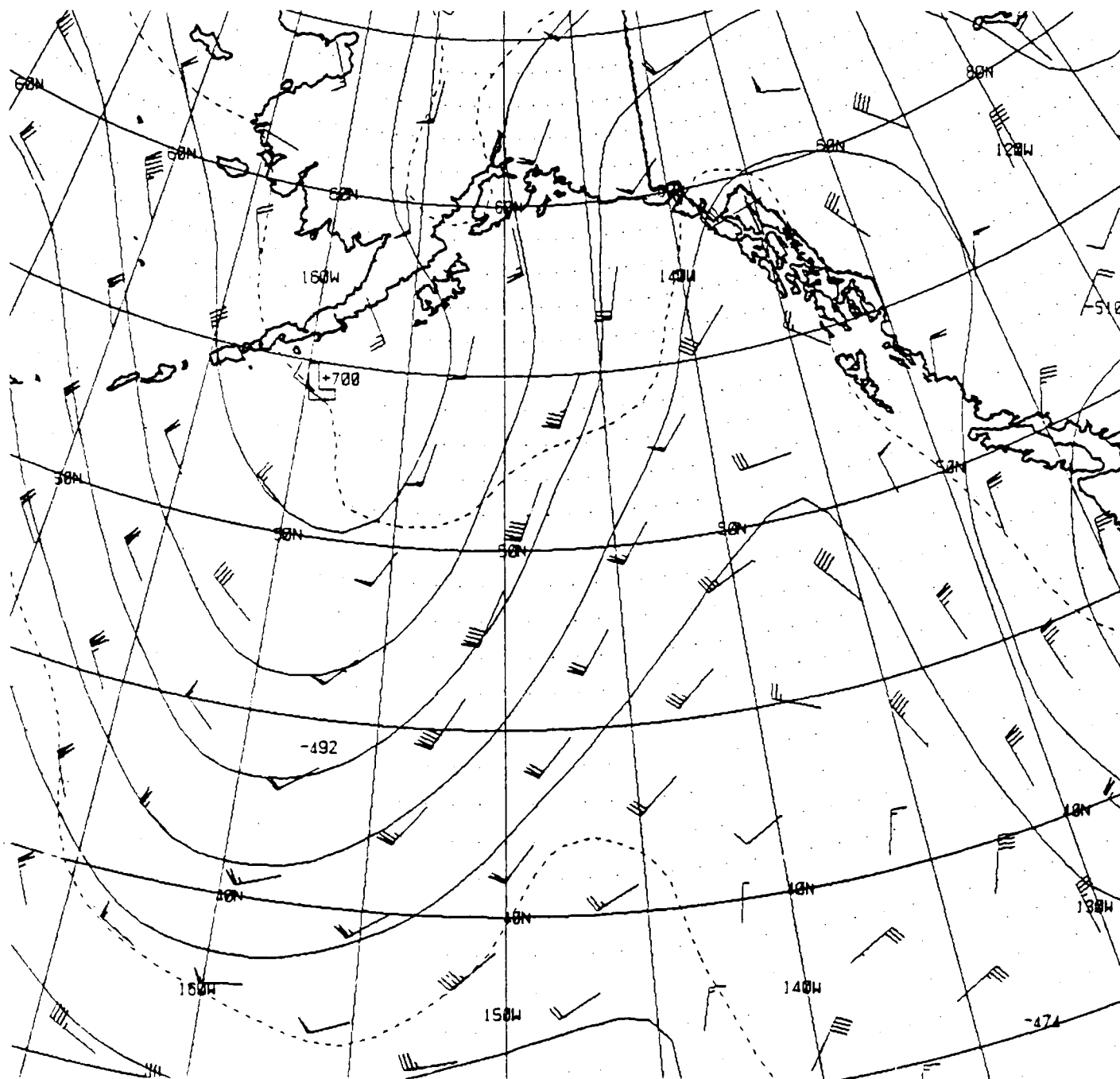


Figure 20. 300 mb analysis for 12Z, 15 Apr 91.



Figure 21. GOES infrared image for 1831Z, 15 Apr 91.



Figure 22a. GOES water vapor image for 1701Z, 15 Apr 91.





Figure 22b. GOES water vapor image for 2201Z, 15 Apr 91.

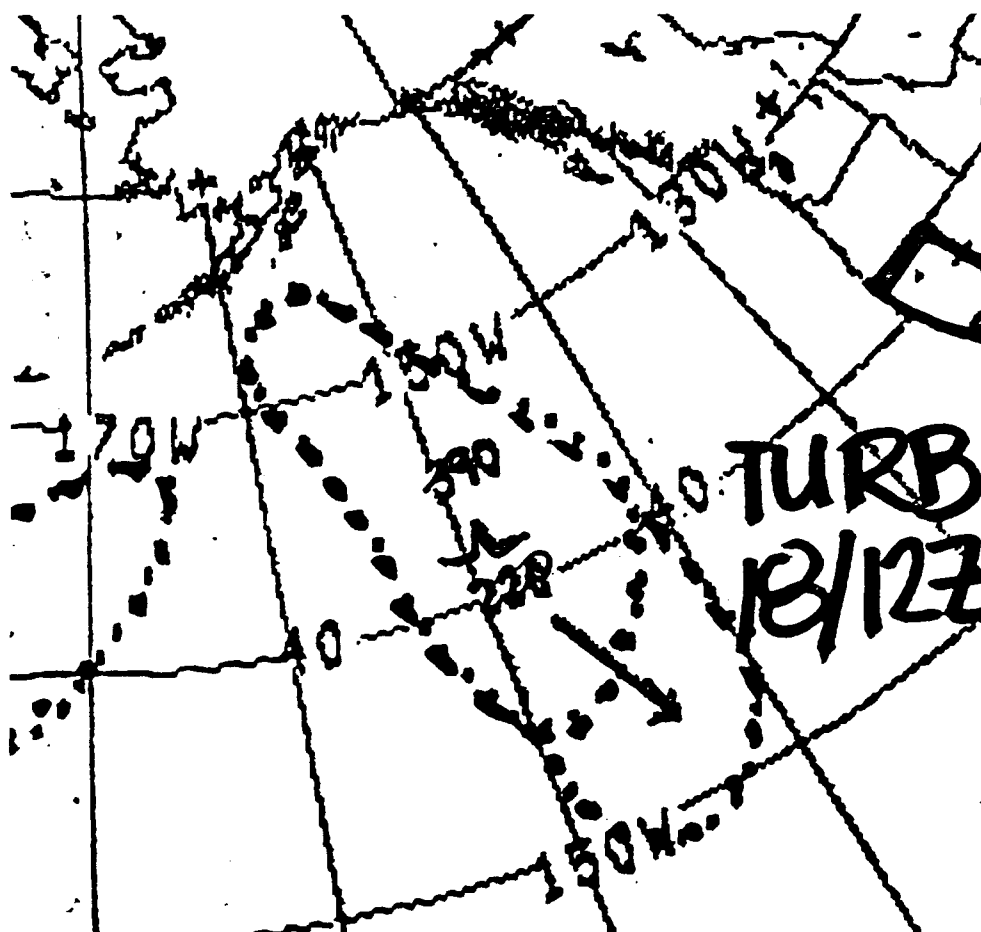


Figure 23. U.S. Air Force turbulence chart valid for 21Z, 17 Apr 91 to 12Z, 18 Apr 91.

Author: Sharply curved (Figure 20)

2: Which type of sharply curved flow?

Author: Ridge (Figure 20)

3: Are there well-defined transverse bands near the upper ridge axis?

Author: Transverse bands absent (Figure 21)

4: Does the region have mountains?

Author: Smaller, less-steep mountains or flat terrain

ExperCAT forecast: No significant CAT, 80% confidence

### 3.7 Case 7

Moderate turbulence (22,000 ft to 39,000 ft) was marked for an area above the Pacific Ocean (approx. 145W, 40N) and valid from 21Z on 17 Apr 91 to 12Z on 18 Apr 91 (Figure 23). GOES images from 15Z to 20Z on 17 Apr were available along with a 300 mb chart from 12Z on 17 Apr and a "forecast" chart from 00Z Apr 18. The interactive session (time: 21Z Apr 17):

Question 1: Which describes the upper synoptic flow pattern?

RB: Sharply curved (Figure 24)

2: Which type of sharply curved flow?

RB: Trough (Figure 24)

3: Which of these are present?

RB: Darkening zone in water vapor image along or upstream from trough (Figure 25a-c)

ExperCAT forecast: Moderate or greater, 80% confidence

This forecast is in agreement with the USAF turbulence chart.

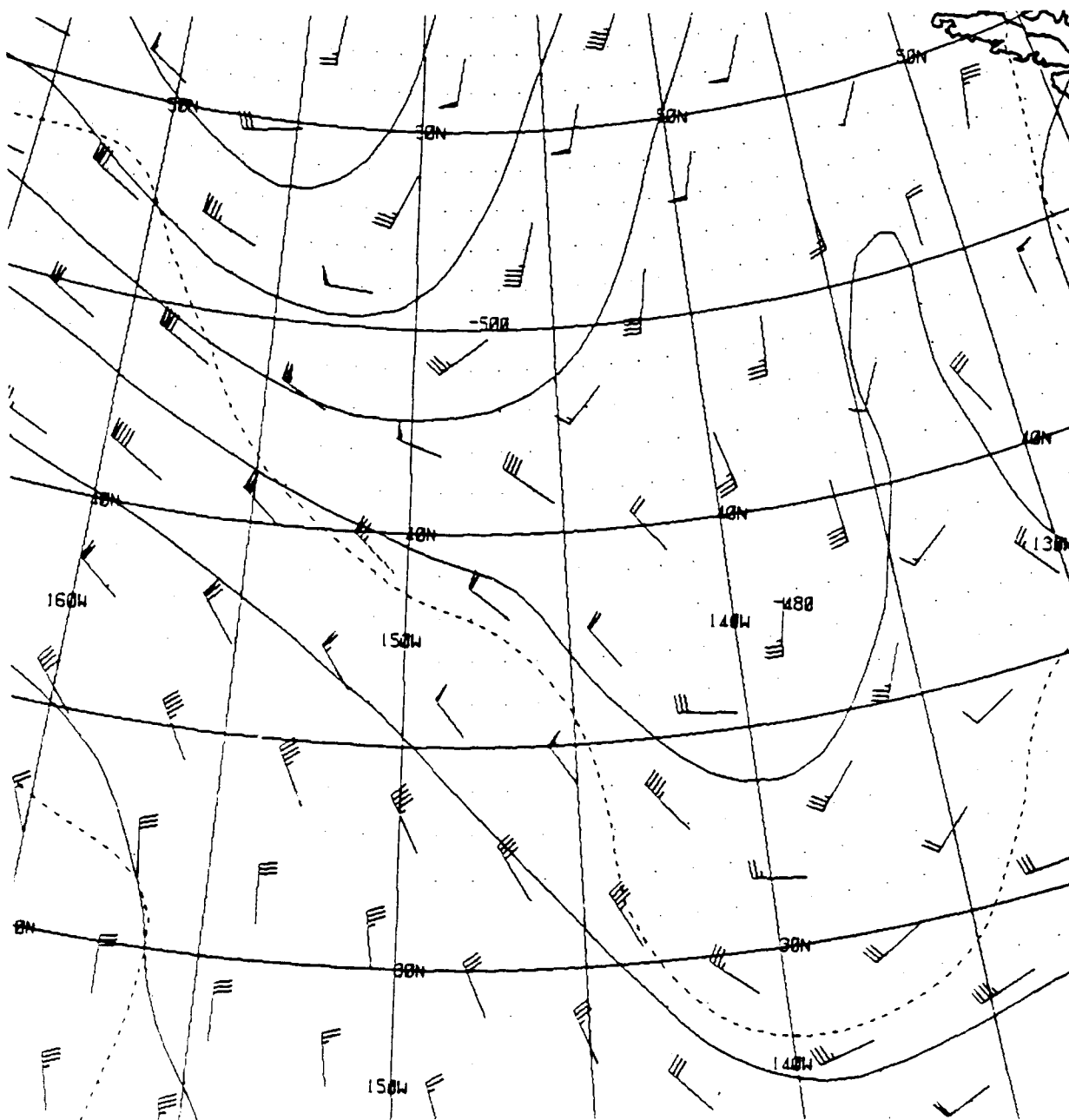


Figure 24. 300 mb analysis for 12Z, 17 Apr 91.



Figure 25a. GOES water vapor image for 1501Z, 17 Apr 91.

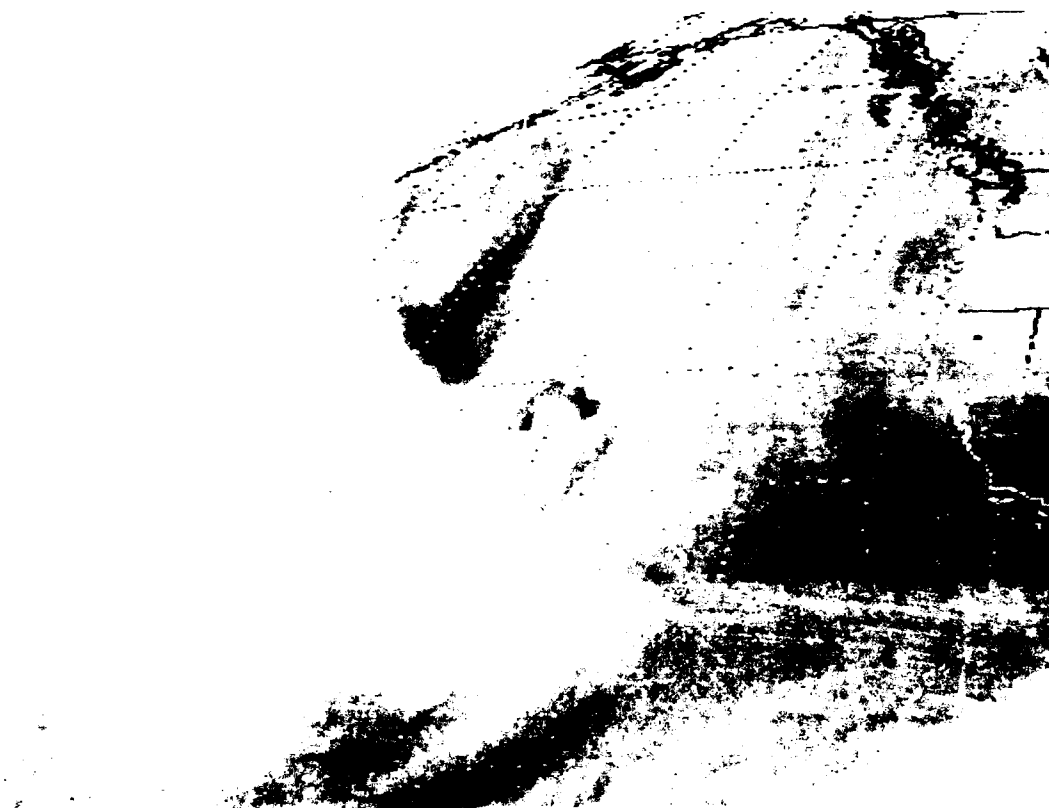


Figure 25b. GOES water vapor image for 1601Z, 17 Apr 91.

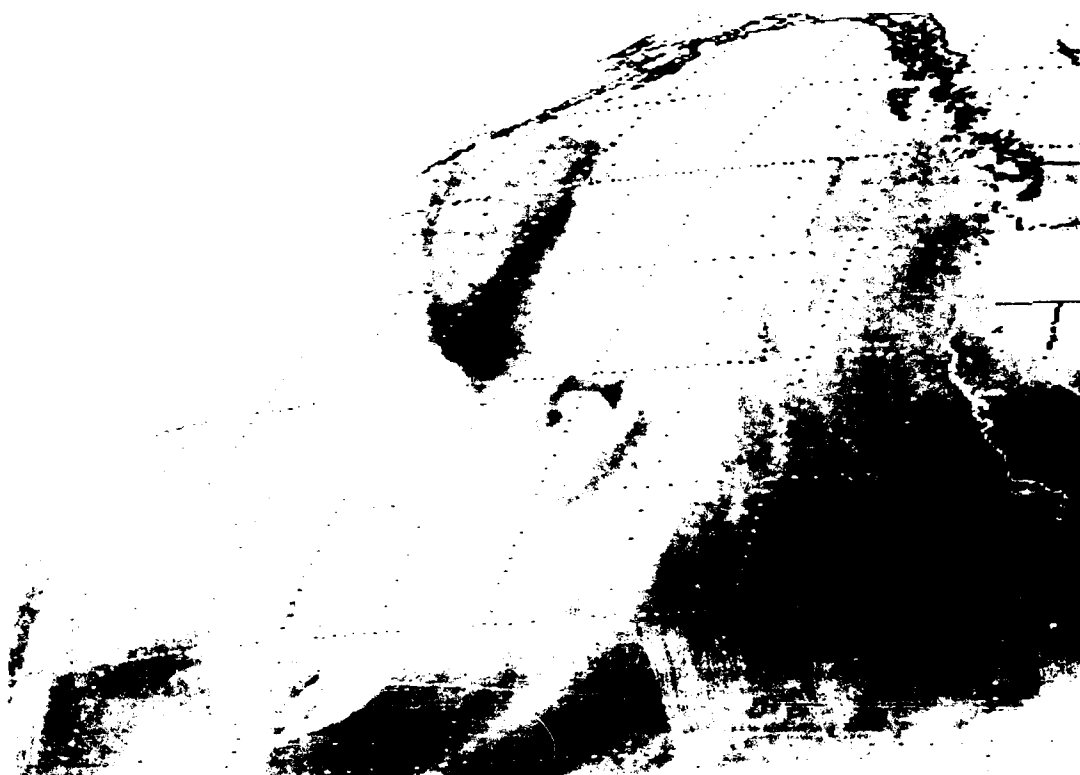


Figure 25c. GOES water vapor image for 1701Z, 17 Apr 91.

#### **4. Conclusions and Recommendations**

ExperCAT, based on a decision tree designed by Ellrod (1989), was developed as a tool for the analysis and prediction of clear air turbulence (CAT). This expert system requires information revealed primarily through user satellite imagery interpretation. An attempt is made in this report to evaluate ExperCAT through an intercompaison of USAF turbulence charts and ExperCAT output.

Seven cases from April 1991 were examined. An area of moderate turbulence was marked for each case on a USAF chart and valid for a 15 hour time period. These seven cases were chosen as a result of the availability of appropriate GOES images. Agreement between ExperCAT and the turbulence charts occurred in 5 of the 7 cases. Possible explanations of the two cases that resulted in disagreement include 1) ExperCAT providing a more detailed analysis than the USAF charts, 2) ExperCAT being supplied with erroneous data due to the low quantity and/or poor quality of the GOES images, and 3) ExperCAT developed with insufficient rule base.

The overall evaluation of ExperCAT by Mr. R. Brody (NRL Monterey) as the end user in this examination was a positive one. He found the system demonstrated an ability, in certain scenarios, to begin with a general outline of a particular situation and give a detailed description of where in the flow pattern to expect CAT. Also, when the user is lacking confidence in image interpretation, the questions themselves can supply clues to determine if the user is providing the most appropriate

answer(s). The user, if necessary, can retrace some or all of the steps already made and answer those questions again. Mr. Brody made two suggestions that would provide help to the beginning user. One suggestion is to provide a note in the introductory screen that reminds the user to determine the general synoptic pattern of the upper air flow and not the flow pattern at the exact point of interest. For example, the forecast area may be on the east side of a high amplitude trough where the flow is relatively straight, but the synoptic pattern is actually sharply curved. A second suggestion is the addition of a help screen that has a list of the satellite signatures that lead to moderate or greater CAT. This list would provide the beginning user with insight into what he or she should be looking for in the images.

Based on the author's overall review, there are other improvements that would provide the user with additional help, explanation, and knowledge. The introductory screen could include a statement on the intended users of the system. Experience in satellite image interpretation and examining synoptic charts are required of any potential user of ExperCAT. An explanation on the confidence levels that are provided with the forecasts would increase the user's understanding of the output. This explanation could also be part of the introductory screen. The reasoning summary available for viewing at the end of a session could be expanded to include "deeper" knowledge. This type of explanation can include the physical reasoning behind the satellite signatures to the cause of CAT. This augmentation would enhance the user's understanding of the system's rule base

which in turn would increase the user's confidence in the output of ExperCAT. Increasing the confidence would increase the amount of usage the system receives. This type of facility would also provide a means of educating the operational meteorologist in this knowledge domain. One possible interface setup for this explanation facility is having two accessible windows:

F1: ExperCAT Facts      F2: Deep Knowledge.

Finally, an instruction placed on the final screen on how to return to the first menu would be helpful. An example:

"Hit Return to Continue."

Limitations of ExperCAT seem to be determined by the quantity and quality of the satellite images. Poor quality can result in the misinterpretation of the data. Overlooking important signatures can result when certain images are not available.



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